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Characterization of matrix and isolated organic solar cells

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ABSTRACT

P3HT:PCBM bulk heterojunction solar cells were fabricated in two different configurations and were compared. A solar cell in matrix configuration showed lower R_s, R_{sh}, and V_{oc} than an isolated cell due to the increased number of parasitic paths through neighboring devices. Solar cells in the matrix configuration were simulated using discrete cell parameters and the J_{sc} obtained was corroborated with experimental value. The PEDOT:PSS layer enhances the effect of lateral charge transport and results in cross-talk-like behavior between arrays of solar cells with a common anode. These lead to significant errors, as high as 72.1%, in the calculated power conversion efficiencies.

1. Introduction

The present technology of inorganic photovoltaic cells is relatively costly limiting their use to military and space applications in many countries. In this context, polymer solar cells become very important with potential advantages such as having lower cost, low energy payback time, low-temperature fabrication process, large area processing on flexible substrates, and the availability of a wide variety of materials. At the same time, they have certain drawbacks such as low efficiency and fast degradation. Bulk heterojunction solar cells using poly-(3-hexylthiophene) (P3HT) and [6,6]-phenyl C61-butyric acid methyl ester (PCBM) are one of the most widely studied polymer solar cells. Theoretical calculations show that the ultimate efficiency possible for a solar cell with a single P3HT:PCBM bulk heterojunction is 11% [1]. At present, the highest reported efficiency for a polymer solar cell using P3HT:PCBM combination is only ~5% [2] (~6.5% for tandem solar cell [3]). Further work is necessary, especially in the areas of tuning energy levels of the C60 derivatives, using low band gap polymers to harvest wider spectrum of the sun light [4], improving the morphology of blends [5], and using various alternative methods like double cable polymers and hybrid solar cells [6], to achieve this efficiency. Stability of organic materials is another important issue which limits their use in solar cell applications [7]. Much of the research work is focused on these aspects in the race to achieve the ultimate efficiency. Most recently, some of the efficiencies reported were controversial [8] prompting the research community to look into the aspect of accurate and standard efficiency determination procedures [9].

Since the processing techniques for polymer solar cells are considerably different from their inorganic counterparts, one should also focus on their characterization in a way as to minimize errors in reported efficiency values. Typically, multiple solar cells are fabricated on single substrate by many research groups [10]. While characterizing such cells, significant measurement errors may arise due to the usage of common electrodes. One of the most common practices in fabricating polymer solar cells is the usage of a thin layer of transparent and conducting polymer, poly (3,4-ethylenedioxythiophene)-poly (styrenesulfonate) (PEDOT:PSS). The PEDOT:PSS layer is used between the indium tin oxide anode and active layer in the solar cells (Fig. 1) The PEDOT:PSS layer improves hole injection, prevents indium diffusion into the active layer, and reduces the anode surface roughness. However, this layer has a finite sheet resistance which results in a parasitic conducting path between neighboring cells of a matrix. This has an effect on the photovoltaic behavior of the solar cells in the array configuration.

This effect in many ways is similar to the cross-talk observed in passive matrix arrays used commonly for organic light-emitting diode (OLED), liquid crystal displays, and flat panel image sensors [11]. The performance of the cells should depend on the distance between the cells in the array and the pattern in which the cells are connected. In addition to differences in the electrical characteristics in dark, there will also be a performance

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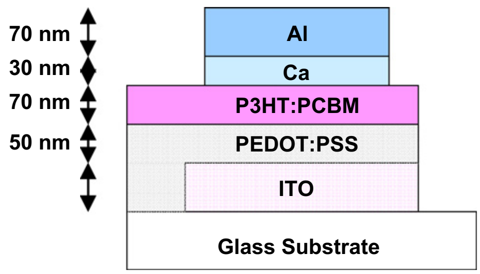

Fig. 1. Cross-section of the P3HT:PCBM solar cell.

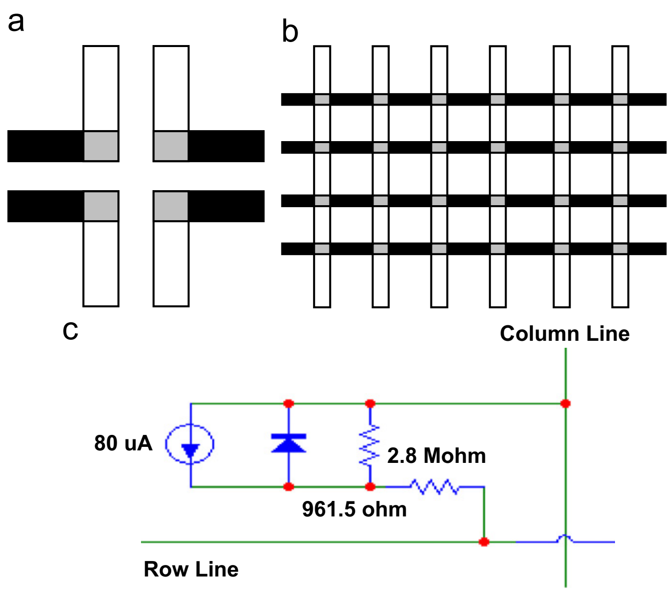

Fig. 2. (a) Individual isolated solar cells and (b) solar cells connected in a 6 × 4 matrix configuration. The white lines represent Ca/Al cathodes while the black lines represent ITO anodes. Each isolated cell has an area of 20 mm^2. In the matrix arrangement, each device has an area of 4 mm^2. The substrate has an area of 25 mm × 25 mm. The solar cells are located at the intersection of these lines. (c) The equivalent circuit used for each cell in our simulation. The diode used in this circuit is assumed to be ideal. The other circuit component values used are assumed to be those of an isolated cell.

differences in the presence of light because the PEDOT:PSS layer, will influence the lateral charge separation process in the solar cells [12].

In this paper, we report the performance of individual P3HT and PCBM bulk heterojunction solar cells fabricated in two different configurations (i) as isolated solar cells as shown in Fig. 2(a) and (ii) as a part of array in a matrix form as shown in Fig. 2(b). The equivalent circuit for each cell of the 6 × 4 matrix configuration is also shown in Fig. 2(c). Current density–voltage (*J–V*) characteristics of these devices were analyzed to determine the reasons for different performances in light and dark.

2. Experiment

Indium tin oxide (ITO)-coated glass substrates were patterned in two different configurations and ozonized for 90 min. The thickness and roughness of ITO were measured to be 110 and 10 nm, respectively, using a Tencor Alpha Step 500 thickness profilometer. The size of the substrates was 25 mm × 25 mm. ITO was used as the anode. PEDOT:PSS was spin coated on these substrates and the substrates were dried in nitrogen atmosphere. A blend of P3HT and PCBM was made in chlorobenzene in weight ratio of 1:1 and was spin coated on the PEDOT:PSS layer. The substrates were vacuum dried for 60 min. The thicknesses of PEDOT:PSS and P3HT:PCBM layers were 50 nm and 70 nm, respectively. Calcium and aluminium were thermally evaporated at a pressure of less than 5 × 10^{-6} mbar to form the cathode. These metals were deposited through two different hard masks to form the cathode lines as shown in Figs. 2(a) and (b). The deposition rates were maintained to be less than 0.1 nm s^{-1}. The thicknesses of Ca and Al layers were 30 and 70 nm, respectively. The reason for using Ca electrode is because the work function of Ca is low. This gives higher built-in voltage which will eventually help in improving the J_{sc} of the solar cell. The layer of Al is used as a protective layer to Ca since Ca oxidizes readily in air. Also, the conductivity of Al is higher than Ca giving a positive effect on the series resistance of the solar cell. The devices were encapsulated in a nitrogen atmosphere. The areas of each cell in matrix and isolated configurations were 4 mm^2 and 20 mm^2, respectively.

Electrical characterization of the encapsulated devices was performed in air ambient using a Keithley 4200 semiconductor characterization system and an Oriel solar simulator operating at an intensity of 84.4 mW cm^{-2} using A.M. 1.5D filter.

3. Results and discussion

The *J–V* characteristics of the devices in dark and light are shown in Figs. 3 and 4, respectively. A comparison of important solar cell parameters is shown in Table 1.

3.1. Dark characteristics

Since both the matrix cell and isolated cell were fabricated under same conditions with same device fabrication parameters, they are expected to have similar current densities for same bias. However, at a forward bias voltage of 5 V, a cell in the matrix configuration gives a current density of 65 mA cm^{-2}, whereas, that in isolation, gives a current density of only 2.8 mA cm^{-2} i.e. the discrete cell current is 23 times lower than that located in a matrix. One can expect this kind of value since there are a total of 24 cells in the 6 × 4 matrix and each of the cells can conduct through the parasitic parallel and series resistance paths. This shows that other cells in the matrix also contribute to the total current though they are not connected. The lateral spread of bias through PEDOT:PSS layer is thus more effective in the matrix

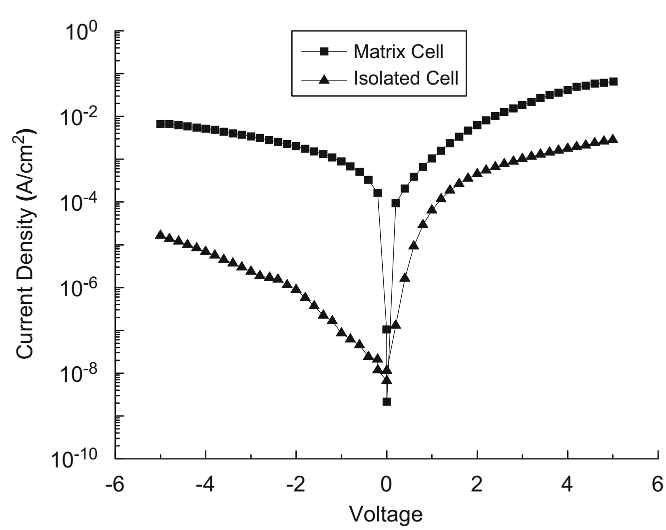

Fig. 3. Comparison of dark characteristics of the matrix and isolated cell. The matrix cell shows a poor rectification behavior with an on/off ratio of only 1.17 at 1 V where as the isolated cell shows an on/off ratio of 751.